Fuel Gas Supply System for Gas Power Plants

Introduction

Natural gas fueled power plants are gaining increasing importance as they are lower carbon emitting in electric power generation. Large size natural gas supply station next to a power plant is a common sight for this reason. These gas stations are equipped with many critical devices such as pressure regulating devices, overpressure protection devices, filtration modules, flow metering, gas composition analyzers, dew point control mechanisms, heaters, etc.

This is to ensure the gas turbines in the power plants receive right quality fuel gas at right quantity and at right time. Understanding the purpose and operation of each equipment installed in this fuel gas supply system is essential for power plant operators to ensure reliability, performance, and safety of the fuel gas system and power plant.

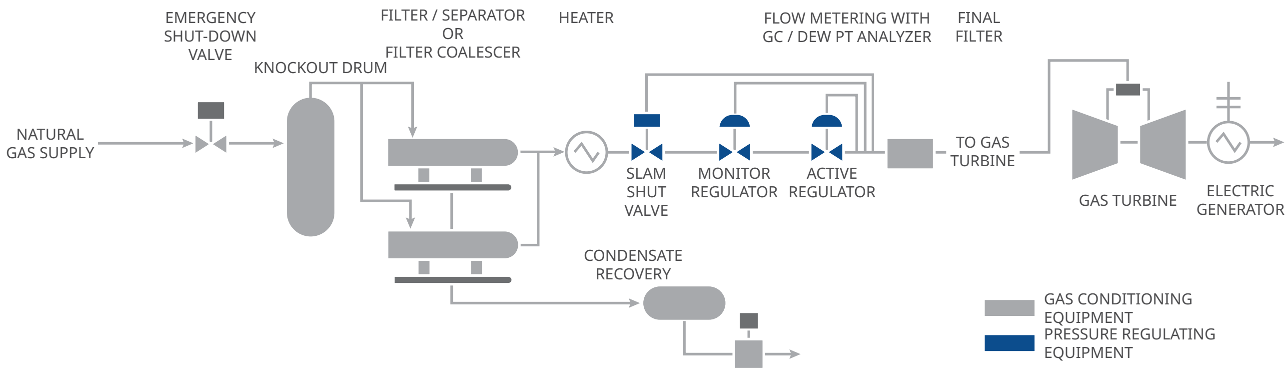


Figure 1. Improved Fuel Gas Quality Increases Valuable Equipment Life

Contamination limits for particulates are established to prevent fouling and excessive erosion of hot gaspath parts, erosion and plugging of combustion fuel nozzles and erosion of the gas fuel system controlvalves. The utilization of gas filtration or inertial separation is instrumental in ensuring that the particulate limits are met.

The introduction of liquids with gas fuel can result in nuisance and/or hardware damage. These include rapid excursions in firing temperature and gas turbine load, primary zone re-ignition and flashback of premixed flames. In severe conditions, liquid carryover to the first stage turbine nozzle may result in damage to downstream hot gas path components. When liquids are identified in the gas fuel supply, phase separation and heating must be employed to achieve the required superheat level. There are several concerns relative to the levels of sulfur contained in the fuel gas supply. This not only affects the gas turbine but also the associated equipment and emissions requirements.

Coal plants have historically provided the largest share of electric power generation, while nuclear, natural gas, and hydroelectric plants provided supplemental capacity. As corporates and governments embark their sustainability and decarbonization goals, meet local and international regulations that restrict greenhouse gas emissions into atmosphere, the largest portion of electric power generation is shifting to natural gas. According to the Energy Information Administration, natural gas surpassed coal as the largest power generation type in the United States in 2016; by 2025, natural gas fueled power plants will supply 41% of the electricity capacity in the United Sates. Of the natural gas capacity, combined cycle plants comprise 53%, combustion turbine 28%, and steam turbines 17%.

Application Overview

Natural gas fueled power plants typically get gas from a nearby transmission pipeline that may operate at pressures from 150 to over 1000 psig. The gas turbines in power plants typically need fuel gas at pressures from 450 to 600 psig. These high pressures, along with high flow required to feed the power plant, use of large size pilot-operated pressure regulators in the fuel gas supply system is quite common.

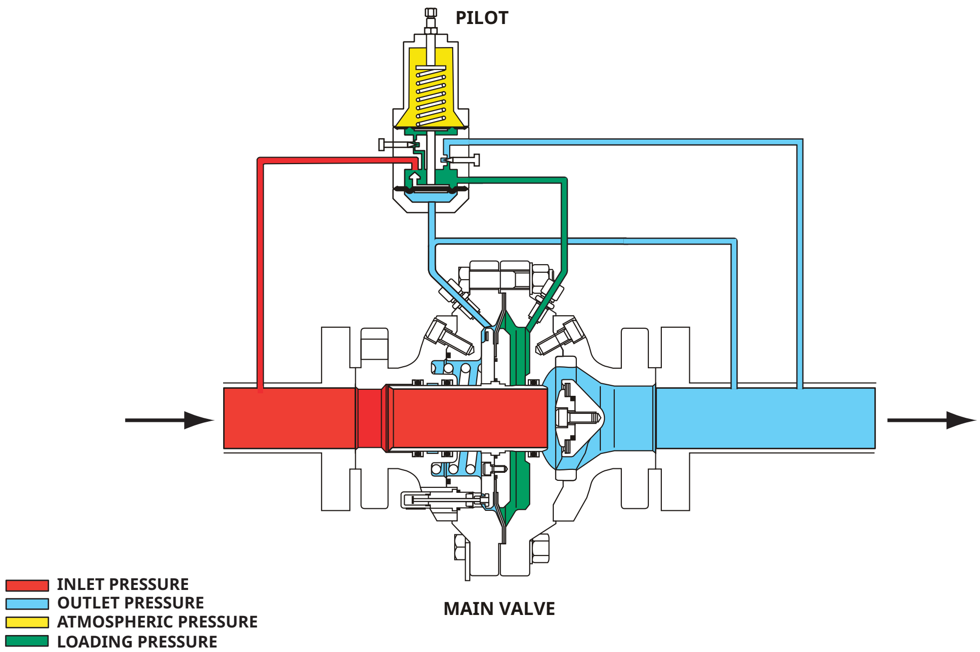


Figure 2. Tartarini™ Type FL - Axial Flow, Two-Path Style Pilot-Operated Regulator

Pilot-operated regulators are self-contained mechanical devices that reduce pressure to a desired set value. These devices self operate by detecting the pressure differential that occurs when there is a change in demand at downstream. No electrical power or instrument air is needed. Pilot-operated regulators can maintain a set pressure accuracy of 0.5% to 2.5%, even when flow rates and transmission line pressures vary. This helps to maintain the desired pressure for feeding the power plant's gas turbines.

Principle of Operation

Pilot-operated regulators have two major components: a pilot valve and a main valve. The pilot is the sensory component and controls the opening and closing of the main valve. The main valve includes an actuator linked to main valve through which the gas flows. Two styles of pilot-operated regulators are available: 1) two-path, loading style and 2) boot, unloading style. Both styles provide reliable pressure control, but the two-path style best meets the high pressure and large flow requirements. In a two-path loading style regulator, if the downstream pressure decreases because demand for fuel gas is increasing, the pilot valve plug moves away from the orifice allowing inlet pressure to fill the loading pressure chamber of the main valve. This increase in loading pressure forces the main valve to open, which increases gas flow to downstream, ensuring downstream pressure remains near the setpoint. If downstream pressure increases because demand for fuel gas is decreasing, the inverse process will occur. The pilot valve plug moves towards the orifice, restricting flow to the loading pressure chamber and forcing elevated gas pressure within the loading pressure chamber to pass downstream through a fixed restriction. When loading pressure is reduced, the main valve's spring forces the main plug to close, restricting gas flow to downstream and ensuring downstream pressure remains near the setpoint.

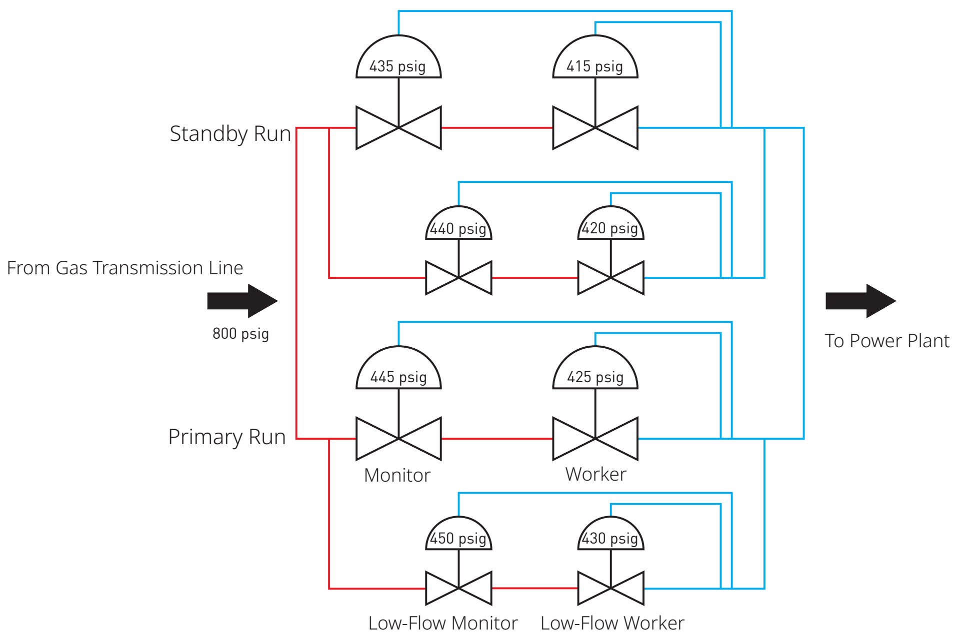


Figure 3. Fuel Gas Supply Station Example

Reliability

The primary goal of a fuel gas supply station is to reliably maintain fuel gas pressure to the downstream turbines. If fuel gas pressure to the turbines drops too low or rises too high, the turbine may trip for safety reasons. High fuel gas pressure can cause equipment damage, low fuel pressure can cause incomplete combustion, risk the safety of the plant workers, and cause extended downtime.

Pilot-operated pressure reducing regulators installed in fuel gas supply stations help to ensure reliability by providing uninterrupted fuel gas supply to the turbine's combustion process. The regulator responds quickly and accurately to changing downstream pressures because of its direct operating and two path control design. To increase reliability, fuel gas supply station is often furnished with redundant parallel runs to maximize uptime and enable the station to respond to unexpected events or to enable the plant to perform maintenance on equipment in fuel gas supply station while the power plant is running.

Overpressure and Underpressure Design Considerations

While the mechanical nature of regulators provides long-term reliability, occasional failures can occur, causing overpressure or underpressure to occur at downstream of the fuel gas supply station. These risks can be mitigated by ensuring the fuel gas supply station is designed with overpressure and/or underpressure protections through parallel runs, series regulation, or slam-shut devices. Additionally, instability within the station can be resolved by appropriately sizing the equipment and adhering to installation best-practices.

Underpressure Protection

Pressure reducing regulators are completely mechanical devices that can fail close, partially close, or open. Most pilot-operated regulators have main valves with springs that push them to close which makes them more likely to fail in a closed or partially closed position. To ensure that a ruptured diaphragm in the regulator would not shut down gas feed, many stations have a standby regulator run installed. The setpoint for standby regulator is staggered at a value slightly lower than primary regulator, which prevents the standby regulator from operating during normal conditions.

By setting the standby run at a slightly lower pressure than the primary run, the standby run will stay closed but prepared to open if the downstream pressure decreases below its setpoint for any reason.

In Figure 4, the regulator on the primary run will reduce the pressure from an upstream pressure of 800 psig to a downstream pressure of 440 psig. The regulator on the standby run will stay closed unless the downstream pressure decreases to 420 psig at which time it will begin to open to maintain the downstream pressure at 420 psig.

In addition to protection from underpressure events, a duplicate run will enable operators to perform maintenance on the fuel gas supply station without shutting the power plant down. The fuel gas load can be shifted between runs when preventative or corrective maintenance is required, ensuring an uninterrupted constant feed of fuel gas is available for the power plant.

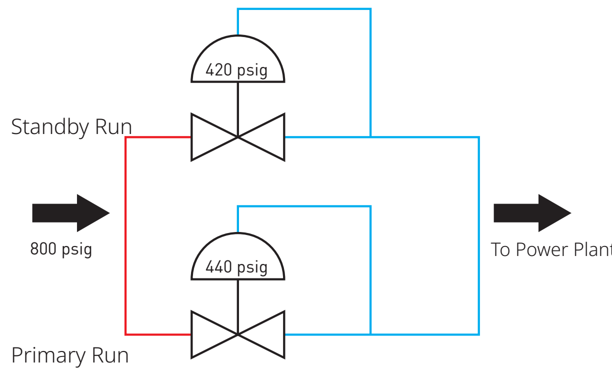


Figure 4. Primary/Standby Setup

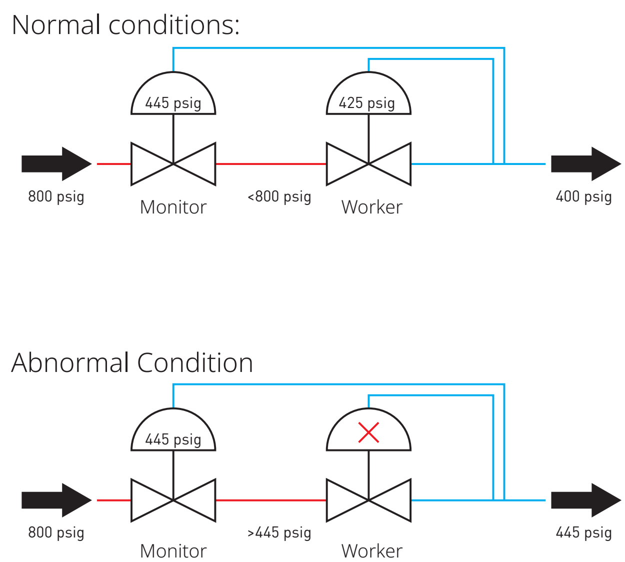


Figure 5. Wide-Open Monitor Setup

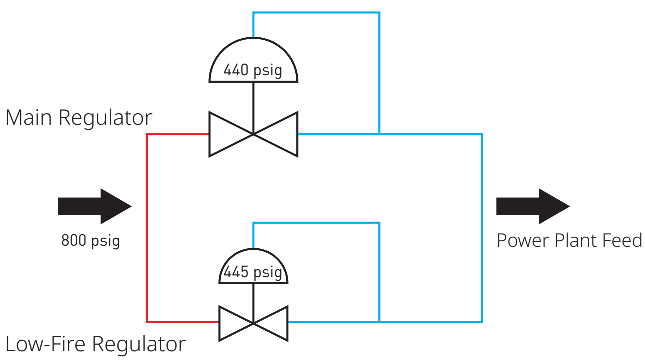


Figure 6. Low-Fire Setup

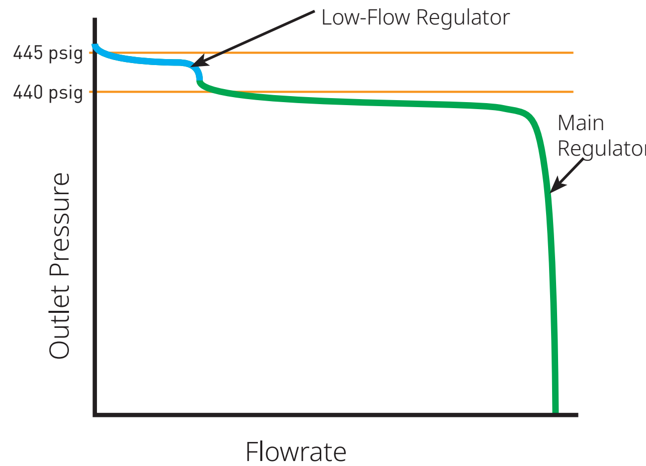


Figure 7. Low-Fire Regulator Setup Behavior

Overpressure Protection

Piping systems in electric power generation stations are governed by ASME 31.1. One of the many areas covered in the code is the application of overpressure protection, or OPP.

For fuel gas distribution systems, the code allows for an alternate design if a full-relieving capacity safety relief valve creates an undue venting hazard.

The alternate methods of overpressure protection are:

1. Tandem Gas Pressure Reducing Valves
2. Trip Stop Valves
3. Safety Relief Valves

The first method is commonly called a “monitor” setup, where two pressure reducing valves can be used in series. They are redundant, but independent pieces of equipment. When one fails, the other will control pressure and maintain it below the system’s limits.

A trip stop valve, or what we call a “slam shut” will rapidly shut prior to the piping’s design pressure from being exceeded, stopping all flow downstream. This is more common in European natural gas systems but is not as widely adopted in other regions because it completely interrupts flow. A safety relief device must be adequately sized to prevent pressure limits from being exceeded under worst-case conditions. Although flow should be maintained, lifting will cause loss of product and emissions concerns

Wide-open monitors are the most common form of overpressure protection in large natural gas distribution applications such as city gate stations, district stations, and large industrial meter sets.

Wide-open monitor configurations place two regulators in series, and both regulators sense downstream pressure via control lines. The monitor regulator’s pressure setpoint is slightly above the worker regulator’s pressure setpoint, maintaining it open and in a standby mode. If the worker malfunctions and downstream pressure rises, the monitor regulator will take control of the run at its pressure setting.

The monitor regulator can be either the upstream or downstream regulator; most important is both regulators must sense the same downstream pressure.

Maintaining Stable Performance

Many regulating stations must accommodate widely deviating maximum and minimum flow requirements. It is usually suboptimal to task a single pressure regulator with managing normal loads, along with low demand loads, such as during plant startup. However, a second, smaller regulator, often called a low-flow regulator, can be added in parallel to handle the lower flow rates at a slightly higher set pressure. The main regulator will pass any flow beyond the low-flow regulator's capacity. A schematic of this setup is shown in Figure 6. Staggering the main regulator and low-flow regulator setpoints ensures that the regulators do not fight for control.
The main regulator should be set at a slightly lower pressure than the low-flow regulator keeping it closed but prepared to open once the flow demand exceeds the low-flow regulator's capability.

Oversizing is the most commonly experienced mistake in regulator selection. When a regulator is oversized, the valve plug tends to stay closer to the orifice, specifically during low flow conditions. The limited plug clearance, coupled with the force of the upstream pressure, causes the regulator to cycle rapidly between open and close. This high frequency cycling or instability, causes wear on the moving parts which can lead to component failure, loss of pressure control, and significant noise. Oversizing is avoided by selecting the smallest orifice size and lightest spring range that meets the maximum flow requirements at the minimum inlet pressure condition.

The load profile of the power plant must be considered when sizing and selecting a low-flow regulator. Because the main regulator must operate at flows exceeding the low-flow regulator's capacity, it is a best practice to select an appropriate transition point between the low-flow regulator and the main regulator. Taking the load profile into account leads to some stations with a much smaller low-flow regulator than main regulator while other stations will be closer in size, sometimes even the same size.

Product Selection Considerations

When selecting pressure control device for power plant fuel gas supply stations, end users and station design engineers should consider the following factors.

Flow

Flow rate is arguably the most important controlled variable for a station feeding a gas-fueled power plant. The flow rate capability of the station must surpass the flow requirements of the plant at maximum load. The flow path within the pressure regulator contribute to the pressure loss across the regulator. This could lower the capacity of the station. Because of these principles, axial flow products have higher flow capacities than top-entry, globe body products of the same size.

Minimum Differential

Understanding the minimum differential pressure required for the operation of a pilot-operated valve is another key consideration when evaluating regulators for gas-fueled power plant feed applications. Minimum transmission line pressures close to the turbine feed pressure can complicate sizing a regulator, because the regulator's minimum required differential pressure may not be achieved in that scenario. Pilot-operated regulators have their published minimum differential requirement to achieve full travel. In general, the larger the actuator diaphragm, the lower the differential pressure requirement. This is one of the reasons why wide-open monitor setups are more common than working monitor setup which take a partial pressure drop across it. A lower pressure drop across the wide-open monitor regulator is important; so, axial flow regulators are commonly used because of their lower minimum differential pressure requirements and efficient flow-paths.

Shutoff

During a plant shutdown, bubble-tight shutoff is required. Ensuring regulators within the station have ANSI Class VIII shutoff rating will increase the safety and performance of the station. Operators should adapt a preventive maintenance schedule to inspect and repair sealing surfaces of the regulator, such as the plug and orifice.

Accuracy

Tight pressure control is a necessity in power plant feed applications. The downstream turbines have high and low-pressure trip points, ensuring proper operation and preventing equipment damage, which would shut down the unit if the delivery pressure is not held within them. Choosing a regulator with tight pressure control accuracy allows the setpoints of the overpressure protection, low-flow regulators, and redundant runs to be set closely together, permitting satisfactory station protection.

Speed of Response

Speed of response is also an important feature to keep in mind while designing fuel gas stations to maintain tight pressure control even during flow demand transitions. Regulators have faster speed of response than control valves which typically receive an external control signal to reposition. Regulators have multiple options for improving speed of response such as pilots designed for quick opening speeds, built-in restrictors, and booster pilots for speeding up closing time.

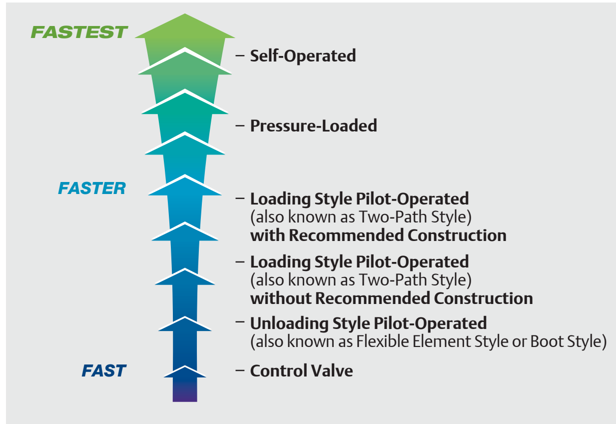


Figure 8. Speed of Response Comparison

Noise

Large pressure drops and high flowrates emit a large amount of noise by nature of the application. This may or may not be an issue based on the location of the station in relation to populated areas or site requirements. Specifications of these stations vary but a common benchmark is about 85 dBA. Turbulence inside the regulator or control valve produces additional noise. Designs with more efficient flow paths, such as axial-flow regulators, produce lesser noise than other designs as shown in Figure 9. Many regulators have noise attenuation trims as options to address noise concerns.

Maintenance

Top-entry regulators with inline maintenance capability offer the best-in-class ease of maintenance. Maintenance tasks can be performed on these units without removing the main body from pipeline. Axial flow regulators, while the maintenance tasks are simple with few pieces, have components that need to be removed from the line to perform full maintenance. Control valves, on the other hand, can have various degrees of challenges when it comes to maintenance. For the control valve to perform optimally, the pneumatic control systems and all electrical components must be adequately maintained.

Emissions

Regulators are self-contained devices: they do not release any natural gas into the atmosphere, which is desirable for minimizing fugitive emissions during operations, unlike control valves. The lost natural gas is an inefficiency that adds costs over time. Further, natural gas (methane) is a green house gas that is undesirable for emission into atmosphere. 1 Kg of methane emitted into atmosphere is equivalent to emitting 25 Kg of carbon dioxide into atmosphere. Figure 10 shows the approximate costs of control valve emissions over time per zero steady-state bleed controller. Normal pneumatic controllers have much higher steady state bleed that would lead to even higher costs.

Position Feedback

Position feedback is available on a variety of regulators to communicate real-time regulator performance. This added feature gives operators an extra indication that the operator is behaving as expected during normal and transient operations.

Additional Overpressure Protection

Overpressure protection is an important aspect of safety as it pertains to these stations. In addition to a wide-open monitor as the primary form of overpressure protection, many choose to protect their equipment and personnel with a second layer of overpressure protection equipment. A relief valve adds a second layer of defense and protects equipment from thermal expansion of trapped gas or regulator leakage.

Furthermore, slam-shut devices are also common overpressure devices used in natural gas stations. These units will completely block downstream flow after an overpressure or underpressure event is sensed downstream.

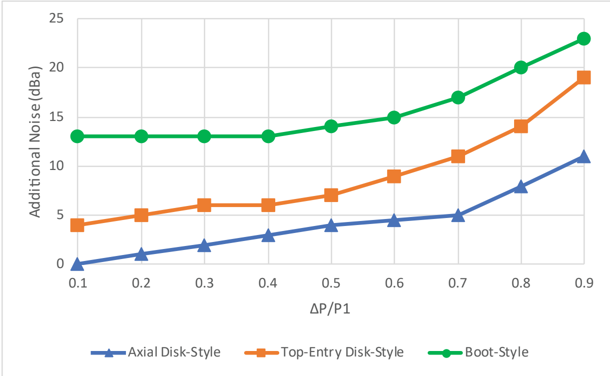
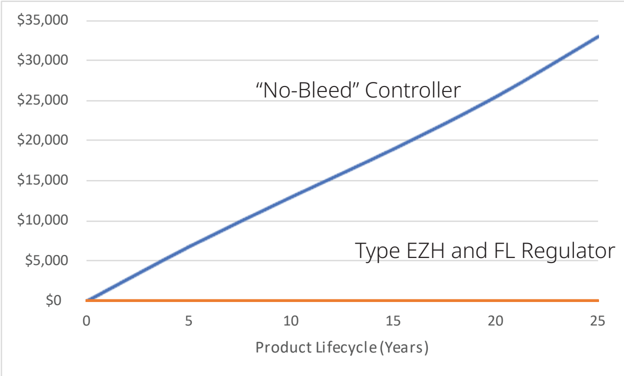


Figure 9. Sound Performance by Regulator Type



1. Source: EPA – Directed Inspection and Maintenance at Gate Stations and Surface Facilities Report
2. Source: EPA – Oil and Natural Gas Sector Pneumatic Devices Report; assuming $7/Mcf natural gas price

Figure 10. Cost of Ownership by Control Device

Many pressure regulator designs offer options to integrate slam shut device in the regulator body. A solenoid valve can also be added to connect the slam shut valve to an existing safety system to form a remote trip, ensuring that the fuel gas station shuts down during an emergency.

Fuel Gas Conditioning

Summary

As natural gas-fueled power plants become more and more common, power plant operators will need to better understand how fuel gas supply stations work. Regulators in these stations are a great option and offer flexibility of station design, ease of maintenance, reliability, and performance. The manufacturer's application team can assist in sizing and selecting regulators for use in these stations to optimally feed the plant throughout its life cycle.

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